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AN EXPLORATION OF NONWORDAL PROGRAMING IN MATHEMATICS AND SCIENCE.

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THIS IS A STUDY OF AUTOINSTRUCTIONAL PROGRAMING IN WHICH THE LINEAR FORMAT REQUIRES SYMBOLIC, NONVERBAL RESPONSES. THE NONVERBAL RESPONSES ARE A SEQUENCE OF TASKS. THE NONVERBAL MATERIAL CONSISTED OF GRAPHIC AND SYMBOLIC REPRESENTATIONS OF VECTORS. SIGNIFICANT DIFFERENCES IN LEARNING BETWEEN GROUPS USING VERBAL AND NONVERBAL PRESENTATIONS OF SIMILAR MATERIAL WERE NOT FOUND. (JK)

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NON-WORDAL PROGRAMING IN MATHEMATICS AND SCIENCE

M. Daniel Smith

While it is obvious that words are powerful tools for learning, they also act to confuse programing research: words mean different things to different people and thus make it difficult to control extraneous variables. Their combination with other stimuli -- graphs, diagrams, mathematical symbols -- introduces complex behaviors not as yet understood, although these behaviors become more important as the use of new media increases. Some of these wordal-non-wordal difficulties were explored and discussed by the investigator in earlier research using conventional linear techniques.[1, 2] Subsequently, using the subject of vectors, sequences were constructed which employed mathematical symbols, graphs, and diagrams only: these are technically "verbal" stimuli according to a recognized analysis in verbal behavior,[3] and thus it has seemed most appropriate to title sequences which use such stimuli (and which exclude words) "non-wordal" rather than using the term "non-verbal" as is customary at present.

In a review of experimental investigations of concept formation, Postman[4] has emphasized that understanding of concepts can precede "verbal awareness"; Bruner[5] has also remarked on this. In the case of concepts which have little similarity to previous experience (as in the present research) the nature of the facilitating effect of words on learning is unclear. The non-wordal (i.e., wordless) stimuli used in this research are similar to stimuli used in certain concept identification research. Walker and Bourne[6] showed the non-linear relationship between learning difficulty and number of nonredunant (relevant and irrelevant) dimensions; dimensions which the

series-to-series progression of the program (used in research reported here) attempts to limit in order to control the amount of information and increase it in a controlled manner. The factor of redundancy is also related to this; this has been the subject of investigations by Bourne and Haygood.[7]

The groupings of types of stimuli, inherent in the "penetration series" of this research, relates to earlier experiments by Kurtz and Hovland[8] and more recently by Peterson:[9] the general superiority of ordered presentation or "homogeneous" presentation reported by them (especially Peterson) implies that the approach adopted here is valid.

Runquist and Hutt[10] found that students learned concepts better from word exemplars than from pictures: however, they found a decrease in differences between treatments as grade levels increased, and this implies that response to non-wordal stimuli can be learned and thereby improved. Runquist and Hutt also point out that the relative effectivenss of the two types of stimuli depends in part on the nature of the concept -- its appropriateness for visual presentation, among other things.

Bourne, Goldstein, and Link[11] have shown that availability of previous information has a positive effect on concept identification; this is taken into account here in part by presenting the information from the problem frame in each subsequent frame, that is, the answer frame for the student and the final answer frame; more complete replication of this study is possible, and will be considered in future experiments.

Such considerations as the above have been invoked by the investigator in a search for a general and powerful approach to the teaching of vectors, one which will condition highly transferable behaviors. Max Beberman in teaching demonstration classes as part of the University of Illinois school

mathematics project, has exhibited what is basically a non-wordal approach, since his oral behavior is mainly horatory and reinforcing. Such groups as the Physical Science Study Committee and the Chemical Bond Approach have emphasized the teaching of behaviors which will be most applicable later on in the rapidly changing world of science. The approach to the introduction to vectors ultimately adopted here resembles closely an approach ordinarily taught in a college course in abstract geometry: the ultimate applications of this approach to physics problems has not been entirely worked out.

Evans[12] and Holland[13] have commented on the importance of "experimental analysis" (as compared with the more popular "experimental design"), where the resulting sequence of learning experiences constitutes part of the data. The outcomes of this analysis cannot be adequately expressed through quantitative statistical reporting: the discovery that a slight change in the fifth frame of a sequence results in an improvement in response to the twenty-sixth or the hundreth frame is something which cannot be adequately described thru conventional statistical procedures. Gagne's[14] hierarchies of concepts and processes emphasizes the value of this point of view; he directs one to search for the simplest approaches which subsume the greatest number of subsequent concepts and processes necessary for the "understanding" of the subject, and he implies that there is a necessary sequence to the presentation. (The investigator's experience leads him to feel that this is an oversimplified view of the actual case, that one cannot set down the hierarchies as clearly as he indicates, and that indeed there are many possible roads to the same result -- many ways of achieving the same "understanding" and thus perhaps parallel structures or "herarchies" which can be employed). The problem in this sense is somewhat analagous to thermodynamics:

there is a given final state, and for each initial state there are several paths which attain the final objective: each of these involves the expenditure of different amounts of work. Wordal and non-wordal sequences may constitute two different paths which may or may not ultimately lead to the same goal: on the other hand, two non-wordal sequences may achieve the same end, but one may be more efficient than the other in that there is less waste energy involved in it.

The research program involved here utilizes a constructed response requirement, since there is at least some indication in programing research that this results in better retention and application when difficult concepts are involved, and because the data which result are much more revealing in relation to the mediating processes involved in incorrect response. The P-Series format (to be described) may be considered a form of branching, a rather thorough and adaptable one which has more depth than simply by-passing, and which does not omit certain important concepts from the sequence covered by faster students (as does the "scrambled" approach). The non-wordal approach may be considered a form of "eg-eg," in contrast to the simple "rul-eg" and "eg-rul" approaches (Glaser, Evans, Homme et al) which have been debated and investigated in the past. The main concern of the investigator has been with problems not of common interest in programing research; one such is the problem of reinforcing responses to the most relevant aspects of the stimulus (where "reinforcing" does <u>not</u> imply seeing the correct response immediately afterward, but is rather a complex function of previous success and confidence in the fact that one's answer is correct, something which precedes the viewing of the correct response and probably precedes the transcriptive behavior involved in constructing the response

itself). Related to this is a concern with the nature of prompting or cuing: the traditional view (proposed by Skinner and associates) is that conditioning here is mainly a matter of shifting stimulus control from an irrelevant or incomplete set of properties (the cue or prompt) to a more relevant or more complete set: this can be viewed as shaping or fading as the situation demands. The approach used in this research is to present the most relevant and limited stimulus situation possible under the given conditions, to challenge the student to apply previous learning as effectively as possible, and then to have him use the correct answer as an additional prompt if he needs it to respond correctly to the next task in the row. This involves shaping, in that irrelevant dimensions must be added from row to row, and also redundancy of relevant dimensions must be varied (here redundnacy is used in a restricted concept-formation experiment sense rather than in the description of degree of homogeneity in presentation as in the title of this research). However, the behavior being shaped include at least some intersection with the sets of behaviors related to "discovery," "responding to challenge," "learning from experience."

A Rationale for the Procedure:

Material to be learned can be divided into an undetermined number of tasks to be required of the student, and these classified along two dimensions: the first dimension represents all those tasks which are alike in complexity or in their demands on mediating behavior; specifically, the number of relevant and irrelevant dimensions is constant and redundant (see Bourne and Haygood[7]). These are symbolized by a row of tasks:

t11, t12, t13, ..., t1n

where "n" is some arbitrary number. Now we may also think of the ongoing process of the learning sequence as being made up of tasks of increased complexity -- this increase may come in the nature of the mediating behavior, or in the number of relevant dimensions involved, or in the number of irrelevant dimensions, or combinations of these. Progress from row to row involves many changes, most of which may be described as the manipulation of irrelevant dimensions.

To continue, the ongoing tasks of the program (or "steps," to use rather popular but rather vague terms) each has its row of similar tasks, and thus the learning tasks for the program are chosen from a matrix of tasks:

T1l, T12, T13, ..., T1n

T21, T22, T23, ..., T2n

.....

Tml, Tm2, Tm3, ..., Tmn

"m" here is also some arbitrary number, representing the last step of the program (some programers would designate this as the "criterion" frame of the sequence, but the problems of evaluation and determining the criterion behavior are not as simple as this view implies). Now the possibilities of presentations suggested by this analysis are legion: a typical linear program, for instance, might be represented as follows:

T11, T21, T31, ..., Tm1

A "bypass" sequence might use T11, T12, T21, T22, ..., with the requirement of Tjk dependent on the outcome of Tj(k-1) -- that is, if correct on Tj(k-1), the student would skip to T(j+1)1. This paradigm applies to a sequence employing three of each row, or four, or more: in the research

carried out so far, there have been four tasks present in each row, and the "response-dependent redundancy" has meant that the student covered Tjk only if he responded to Tj(k-1) incorrectly: if the student responded correctly to Tjk, then he skipped to T(j+1)1.

Another possibility here would be to present the sequence in this order:

T11, T21, T31, ..., Tj1, T12, T22, ..., Tj2, T31,

....., etc.

This would constitute a rudimentary review technique, and would also be similar to homogeneous vs. heterogeneous procedures used in experimentation in concept identification (see Peterson[9]).

Suppose that in a program four tasks are presented from each row, and that students either do a certain number of each (this number being prescribed by the experimenter) or that they have an optional skipping procedure (this could require more than one correct response before skipping): then a similar set of variations is possible in the testing or evaluation procedure which follows the learning. That used in certain of the studies to be described is as follows: first one divides each task "T" into a problem frame "C" (for "criterion") and an answer frame "A": then one has:

Cp4, Cq4, Cs4, ..., Ct4, Ap4, Aq4, As4, ... At4,

Cp5, Cq5, Cs5 ....., Ct5, Ap5, Aq5, etc.

where "p" and "q" are steps selected as criteria from the original sequence to form the test. If there are four examples of each task, one can still gain a "penetration" score even though all students do all tasks on the test: this penetration score is the number of tasks in the row up to and including the first correct response. Since all students do all tasks, one also derives a "consistency" score, that being the number of instances

where a correct response is followed by one or more incorrect responses in the same row of tasks: the relationships between penetration, consistency, and simple errors on this evaluation procedure is one of the areas investigated in this research.

Chronological Description of Procedures and Results (by Phases):

Phase I: Initial linear sequences in vectors became relatively error-free (with only random errors) early in the investigation. However, many differences in speed and confidence shown by subjects, and several paradoxical outcomes involving low error coupled with lack of understanding on criteria, led to a search for more dependable measures of response strength during learning: this also related to a need for better identification of previously learned concepts, since pre-tests were often not sensitive to previous learning. The general objective was the formation of sequences which were error-free (relatively) but also as brief as possible: to use an analogy from thermodynamics, it constituted an attempt to maximize the work of the student by providing an opposing "pressure" which was "infinitesimally less" than that which he could produce.

In order to satisfy the needs described, and to gain a degree of adaptability in respect to different histories of learning and other unanalyzed aspects of "aptitude," it was decided to adopt a rather unusual procedure. Each step of the program was to function as its own pretest and its own remedial sequence: this implied that (a) "step-size" was to be increased and (b) each step or task would be backed up by several other similar tasks, so that the student who responded erroneously to one could correct his behavior by responding correctly on another of the same ...

type. Such a plan was difficult to carry out in practice. Also, two more additions to the format increased this difficulty: first, each answer frame was constructed to include the original problem situation as well as the correct answer (all stimuli were presented on squares of paper, and this made it unnecessary to go back to the problem to check if it was forgotten); second, a separate frame between the problem sheet and the student answer sheet was given in the latest version, to provide a special place for the student to respond (this last addition is a function of the nature of the subject-matter approach used.) Thus each step of the program requires three complete stimulus frames for each example of the task, and contains four tasks which are different representations of the same step -- a total of twelve frames per step. The entire program is about one hundred fifty steps at present.

In the approach just described, different tasks associated with each step relate to a concept formation paradigm, with relevant dimensions held constant and irrelevant ones varied (relevance to concept formation research is described in another section). Figures 1 and 2 illustrates four task frames which are associated with the same task, the whole constituting one "step" of the program: Figure 2 shows a sample of the tasks associated with the following "step."

Phase II: A pilot project involving five students and an earlier version of this program was run in the fall of 1962. Here, each student performed as many tasks in each "step" as he needed in order to respond correctly once: he then skipped to the next "step" (a research assistant acted as a "teaching machine" to control the progress according to this branching technique).

This resulted in data on the number of tasks required at each step, and the mean number of tasks for a given sequence was called the "penetration" score of the student. This score is intuitively related to the difficulty experienced by the student in going through the program: a student who scores 1.32 (i.e. a mean of 1.32 tasks per step required to get a correct response each step) has an easier time with the program than one who has a mean of 2.1. The number of students was small, since this was mainly a test of feasibility: penetration seemed to correlate well with criterion errors during and immediately following the program, but on the delayed-post-test the students with the highest penetration had the lowest relearning scores (the post-test was cast in the same form as the program, thus giving a penetration mean which served as a relearning score). There was some hint of the possibility of an optimal penetration score in learning; these data are presented in Figure 3.

Phase III: After the initial trial the program was revised, and limited investigations of particular variables were designed. One of these investigations compared wordal and non-wordal programing using sequences related to vector equality: a wordal treatment was compared with three successive versions of a non-wordal one, and variations in redundancy ber of tasks required at given steps) constituted the treatments. The (num-final version of the non-wordal sequence was superior to the wordal version (however, the wordal version could have been varied in respect to certain dimensions, and thus might have been improved also). The results are illustrated in Figure 4. These were short sequences, and few subjects were used: however, the nature of the criterion enabled the investigator to ascertain differences in spite of this, and thus it seems worthwhile to describe the criterion used.

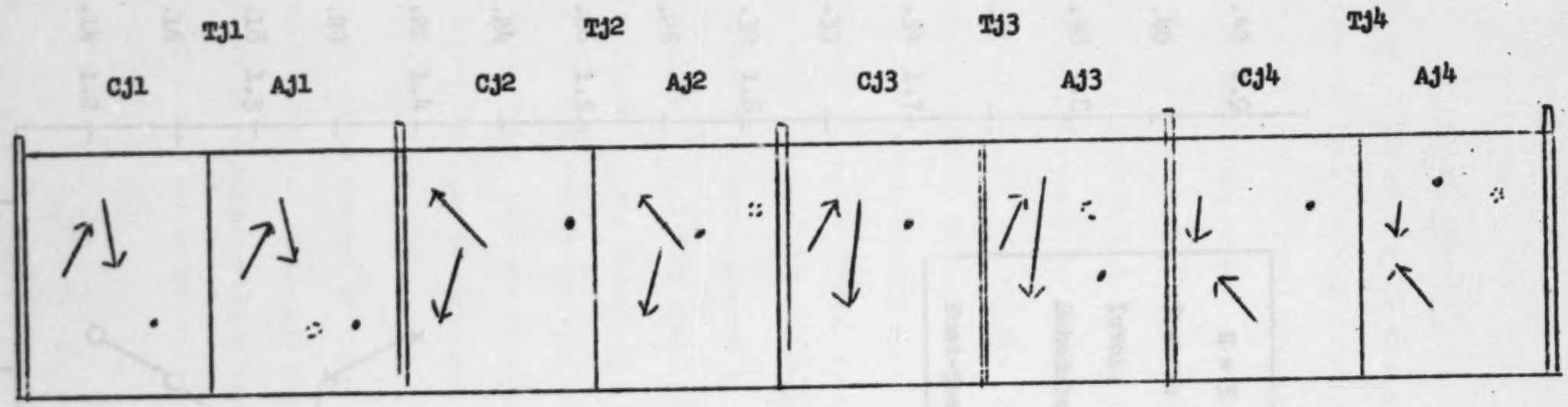


Figure 1

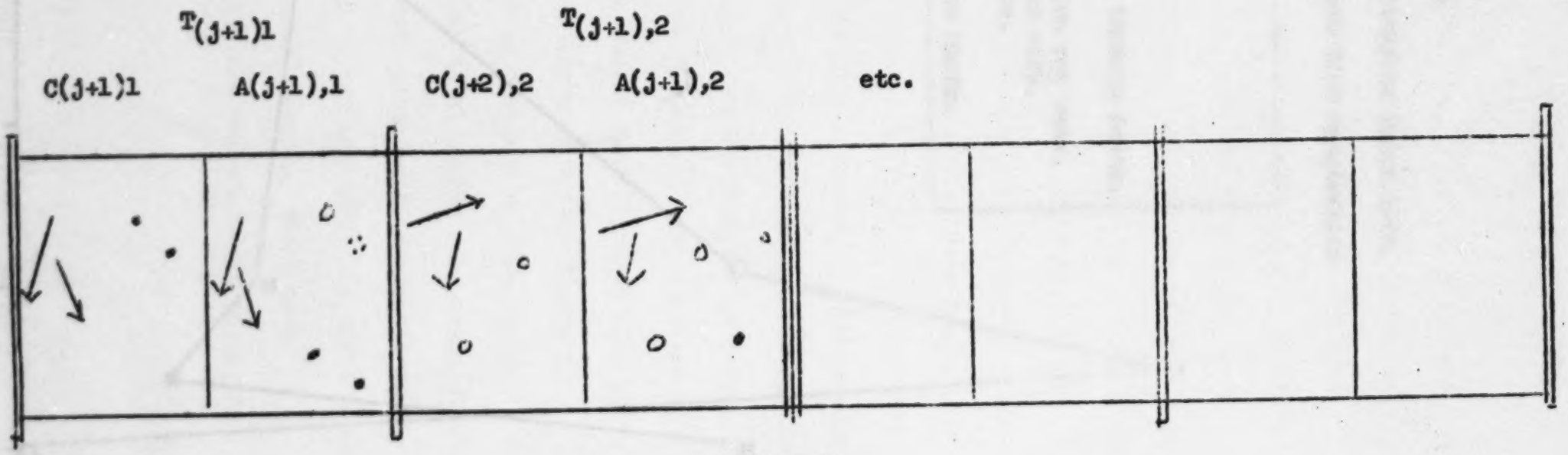
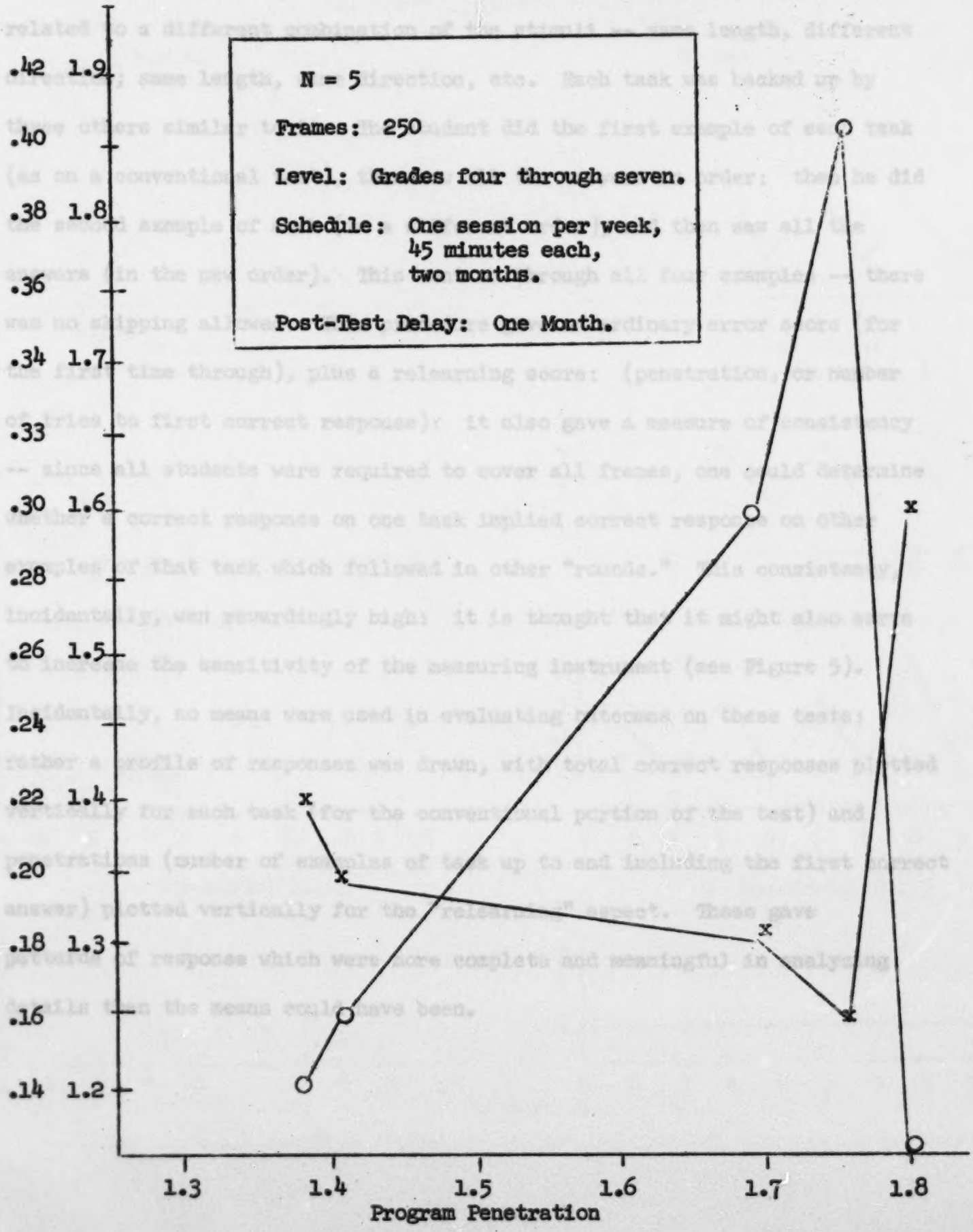


Figure 2

Figure 3

Y' and o Criterion Error Rate

Y" and x Post-Test Penetration

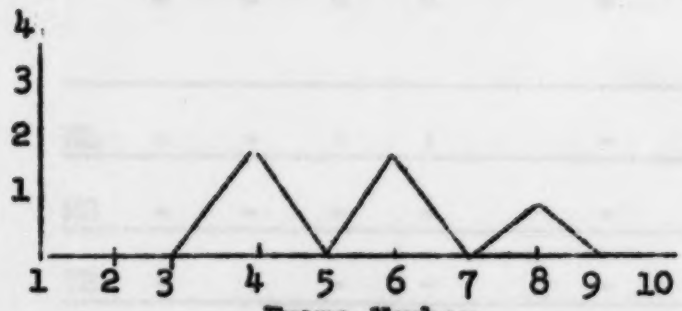


Criterion, Phase III and IV: the criterion test for Phase III and Phase IV was made up of several tasks related to the equality of vectors: some required a wordal response, some a non-wordal response. Each task related to a different combination of the stimuli -- same length, different direction; same length, same direction, etc. Each task was backed up by three others similar to it. The student did the first example of each task (as on a conventional test), then saw all the answers in order: then he did the second example of each (in a different order), and then saw all the answers (in the new order). This went on through all four examples -- there was no skipping allowed. This procedure gave an ordinary error score (for the first time through), plus a relearning score: (penetration, or number of tries to first correct response): it also gave a measure of consistency -- since all students were required to cover all frames, one could determine whether a correct response on one task implied correct response on other examples of that task which followed in other "rounds." This consistency, incidentally, was rewardingly high: it is thought that it might also serve to increase the sensitivity of the measuring instrument (see Figure 5). Incidentally, no means were used in evaluating outcomes on these tests: rather a profile of responses was drawn, with total correct responses plotted vertically for each task (for the conventional portion of the test) and penetrations (number of examples of task up to and including the first correct answer) plotted vertically for the "relearning" aspect. These gave patterns of response which were more complete and meaningful in analyzing details than the means could have been.

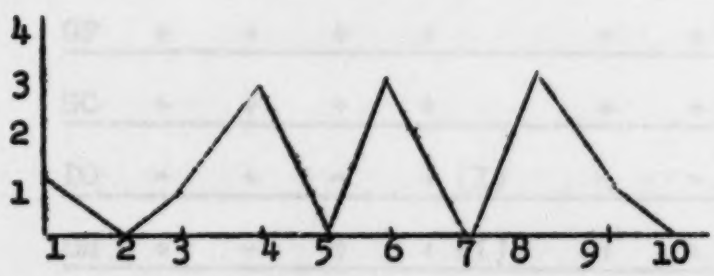
Figure Four

ABBREVIATED POST TEST

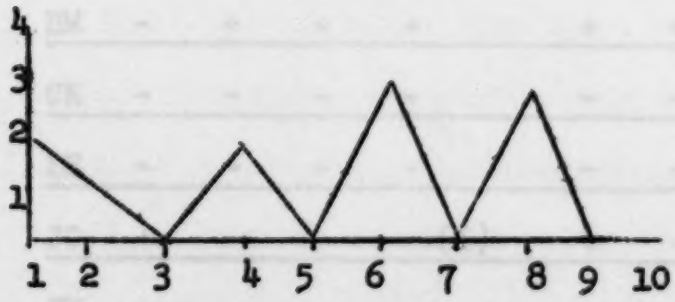
Wordal



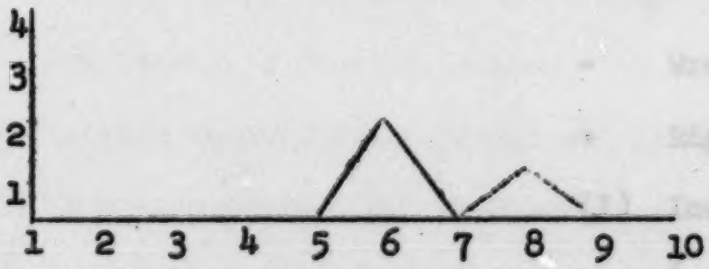
Non-Wordal No. 1



Non-Wordal No. 2

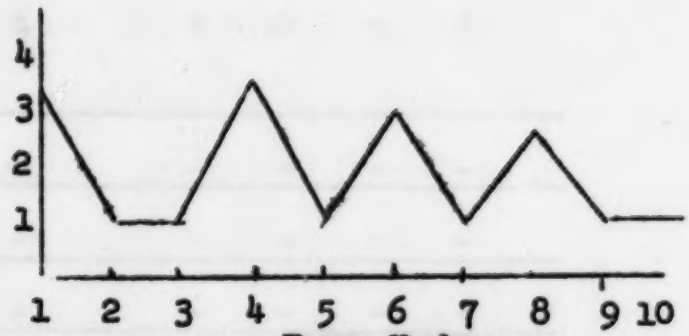


Non-Wordal No. 3

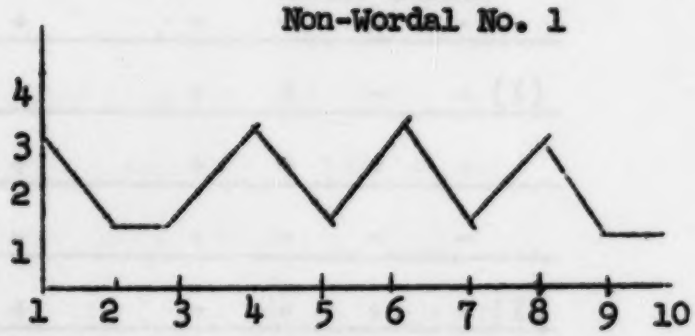


DELAYED POST TEST

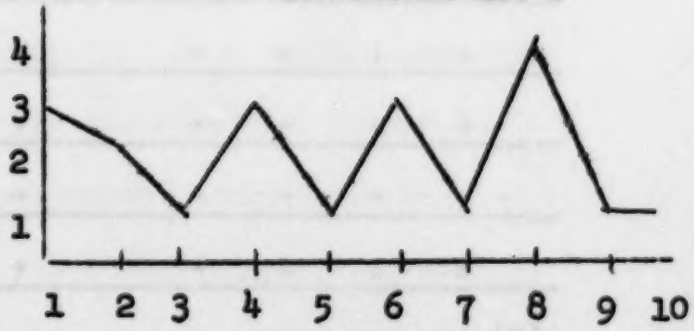
Wordal



Non-Wordal No. 1



Non-Wordal No. 2



Non-Wordal No. 3

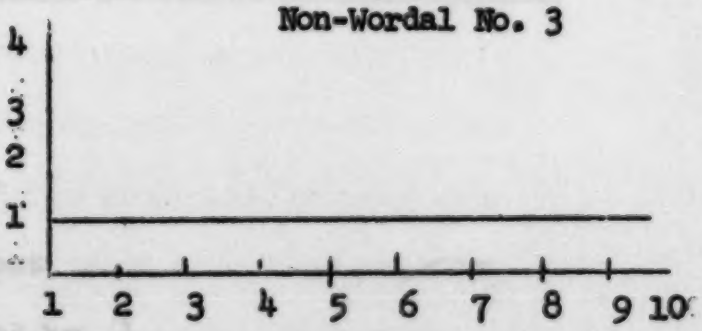


Figure 5

Consistency data from three of the ten delayed post-test items: "$(L\ D)_w$" indicates wordal response.

	$(L\ \overline{D})_w$				$(L\ \overline{D})_{nw}$				$(L\ D\ \overline{L}\ \overline{D})_{nw}$			
	a	b	c	d	a	b	c	d	a	b	c	d
NL	+	+	+	+	-	+	+	+	-	-	-	-
MS	-	-	-	+	-	-	--	-	-	-	-	-
TB	-	-	-	-	-	-	-	-	-	-	-	+
JB	+	+	+	+	+	+	+	+	-	-	-	-
GP	+	+	+	+	+	+	+	+	-	+	-	+ (I)
GC	+	+	+	+	+	+	+	+	+	+	+	+
DO	-	+	-	+ (I)	-	-	-	-	-	-	-	-
SH	+	-	+	+ (I)	+	+	+	+	-	-	+	- (I)
DR	+	+	-	- (I)	-	+	-	- (I)	-	-	-	-
BM	-	-	+	+	+	+	+	+	-	-	+	+
CK	-	-	-	-	-	-	+	+	-	-	+	+
DE	-	-	-	-	-	-	-	-	-	-	-	-
JC	+	-	-	- (I)	+	+	-	+	-	+	+	+
KK	-	-	-	+	-	-	-	-	-	-	+	- (I)

\- Wrong

\+ Right

(I) Inconsistent (+ followed by -)

Some care has been taken in describing the methods used in this early limited experiment comparing wordal and non-wordal treatments, because in this investigation were developed several approaches which should be experimented with further on a larger scale, regardless of the nature of the treatments involved. Most important of these, perhaps, was the variation of the redundancy by invoking specific requirement for different individual steps: for instance, students might be required to do only one, or to get one correct, on one step, and to do two (or do two correctly) on another -- this approach was used to combat previously established concepts which interfered with the learning. Another important outcome was the evaluation procedure just described.

In another small investigation, a search was made for the most effective and also the most general means of introducing students to the concept of a vector. This involved introductory sequences designed to prepare the students to respond. The most successful and general approach involved a concept of vectors as operators: this was used more extensively in Phase IV. In this study there was some indication that wordal sequences were still the most powerful over the periods of the time used in trials with students during the development of the sequence: however, we did not attempt to develop the non-wordal to a point where they rivaled the wordal.

Phase IV: Subsequently the entire program was revised, in P-Series format, using the vector as an operator in introductory sequences: this resulted in a shorter program, but since a student-answer frame was added to each task (which repeated all information) the production process was very time consuming. Also, extra sections were added on the commutative, associative, and distributive properties, since they arose naturally in

the course of learning: these had not been tested prior to this phase, and affected the revised versions of older sequences which follow. The final stages of the program -- introducing ordered pairs, n-tuples, the addition and subtraction of these, and finally matrices -- were not included in this phase due to limitations on time.

The first two sections of the last version of the program was cast in two forms: one was completely without words, the other used in the same non-wordal stimuli (including response requirement) but also included a wordal treatment with its own response requirement: this was designed to call attention to certain crucial aspects of the stimulus. This procedure was adopted to explore the interaction of wordal and non-wordal stimuli in such presentations, and resembled conventional film strip captions and other such additions to visual presentations. The hypothesis was that while the strictly non-wordal frame would be harder to understand initially, students would ultimately be less confused and more able to transfer knowledge as a result of covering these than with the combined non-wordal (graphical-symbolic-diagrammatic) and wordal stimuli. Initial in-class trials were made using five sections of the revised program (I, II, III-a, III-b, III-c). A class of thirty fifth-grade students was introduced to the programing approach involved by means of an introductory booklet using words: this conditioned them to use the P-series format of the experimental program, by use of such mediating sentences as:

"If you do I-A correctly, skip I-B, I-C, and I-D, and go to II-A: if, however, you miss I-A; then do I-B."

This was reviewed before the entire class by the experimenter. Then the first booklet was passed out: half of the first books were non-wordal, and

half were wordal. The new stimulus situation, new subject matter, and new approach to learning combined to produce some initial confusion, thus the first booklet was done over again in the succeeding class two days later. After this, the students settled down and seemed to progress consistently through the materials. Book II was probably the most representative of the potential of the class: as they came into Book III, (where, incidentally, all students had non-wordal programs since only I and II had wordal versions), the cognitive demands of the program began to result in frustration and, subsequently, an increase in "cheating" -- this behavior was difficult to control adequately while also maintaining representative field test conditions. Evidently the students had been conditioned to keep an even, quiet class routine regardless of cognitive dissonance.

Since this was a pilot field test, only rough data are described here and only very tentative conclusions submitted where there seems some reason to make such a statement.

The non-wordal students of course went much more rapidly than those who had a wordal section to each frame: almost all the non-wordal students had passed in their second books and gone on to their third books by the time the wordal people started to finish the second book.

The post-test was administered a month later: the class had not been told that there would be a post-test, and had not had opportunity to review the materials. Close control was invoked in the post-test situation: this was made simpler by the fact that correct answers to the first ten items came in a group, following the first ten problems -- thus, the correct answer was not given following each task, but following the first set of

eleven tasks. The post-test was forty-four items -- four each from eleven categories. Both penetration and consistency scores were obtained: closer examination of these resulted in the drafting of a new statistic, wherein a correct answer on the first example of the set of four was given .5 point, the second 1, the third 1.5, and the last 2: thus there were five points possible, and the greatest weight given to successful relearning of the correct response rather than to initial correct performance on the test.

The program data was collected and analyzed from the point of view of penetration: the penetrations on Book II and on Book III-A were taken individually to be most representative of the difficulty experienced, since the incidence of cheating had increased to too high a level in the opinion of the investigator for any reliance to be placed on later penetrations.

Some Details of Phase IV:

Sample: N = 23 Grade: V Mean IQ: 110 (California Mental Maturity) (F, 11; M, 12)

Sequence: Units I, II, IIIa, IIIb, IIIc of a program introducing vectors as arrows which operate on one or more points, where two arrows operate on the same point in either order. (vector addition). Also commutative and associative properties.

Treatments: Books I and II were cast in two ways: the first was entirely non-verbal, the second was identical with the first in its non-verbal stimulus properties, but also contained a verbal dimension which also required a response on the part of the students. This verbal response was designed to emphasize the unique aspect of the non-verbal stimulus-response relationship.

Books IIIa, IIIb, and IIIc were non-verdal for all students; this was not ideal, but necessary due to the tremendous effort involved in producing the programs, which made the production lag too far to produce verdal versions for the last three books.

Results: (a) A comparison of eight students who had the non-verdal version only (in Books I and II) with eight who had the combined verdal-non-verdal in those books shows the following averages:

	Mean IQ	Mean Arithmetic Aptitude	Mean Post-Test Score	N
Verdal & Non-Verdal	109	4.8	22.3	8
Non-Verdal only	110	5.2	23.4	8

There is evidently little difference between groups here; statistical tests are not applied due to uncontrolled nature of situation.

(b) A comparison of penetrations on Book III-a (which was non-verdal for all) might be expected to show some differences in preparation (via Books I and II) between the verdal-non-verdal group and the non-verdal-only group: five pairs of students matched on the basis of arithmetic aptitude (since this had showed evidence of some correlation with post-test scores on basis of a scatter plot), showed a mean difference of .12 in penetration on Book III-a between the two groups:

this difference favors the non-wordal-only group, but is not significant. The most noticeable difference between the groups was in the matter of time: the non-wordal-only group went far ahead of the other group, since the other group had to make two types of response to each frame instead of one.

(c) Since both groups were mainly non-wordal, having three out of five books or units in the non-wordal-only mode, the over-all averages may be taken as an indication of the effectiveness of this type of introduction. The mean score of more than 22 out of 55 possible points on the post-test, given a month following exposure to this program, indicates that the students did learn from the programs. Whether they learned as much as they would have from a conventional presentation is doubtful; the probability is that they did not, since the non-wordal nature of the stimulus was new, and since the subject matter was not only new but demanding in relation to the materials they were accustomed to. It should be remembered that the test featured relearning -- after seeing eleven review problems they were shown the answers (along with the original problem, of course) and then given eleven more tasks in a different order: scoring favored correct responses on the last items rather than the early ones, since a correct response on the first of the set was scored .5, as compared with 1, 1.5, and 2 on the second, third, and fourth respectively.

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